

Program 9 Inelastic Response of Metal Matrix Composites Under Biaxial Loading

F. Mirzadeh, M.-J. Pindera and C.T. Herakovich

Objectives

The long-term objective of this investigation is aimed at attaining a complete understanding of the inelastic response of metal matrix composites subjected to arbitrary, biaxial load histories. The core of the research program is a series of biaxial tests conducted on different types of advanced metal matrix composite systems using the combined axial/torsional hydraulic load frame in the Composite Mechanics Laboratory at the University. Tests involve primarily tubular specimens and include tension, compression, torsion and combinations of the above load histories in order to critically assess the inelastic response of advanced metal matrix composites in a wide temperature range.

Yielding of SCS-6/Ti-15-3 MMC Under Biaxial Loading

Carl T. Herakovich
Marek-Jerzy Pindera
Farshad Mirzadeh

Department of Civil Engineering

Abstract

Elements of the analytical/experimental program to characterize the response of silicon carbide titanium (SCS-6/Ti-15-3) composite tubes under biaxial loading are outlined. The present investigation is part of a long-term program to investigate the inelastic response of metal matrix composites in a wide temperature range under arbitrary, biaxial loading. The analytical program comprises prediction of initial yielding and subsequent inelastic response of unidirectional and angel-ply silicon carbide titanium tubes using a combined micromechanics approach and laminate analysis. The micromechanics approach is based on the method of cells model and has the capability of generating the effective thermomechanical response of metal matrix composites in the linear and inelastic region in the presence of temperature and time-dependent properties of the individual constituents and imperfect bonding. The preliminary results discussed herein illustrate the effect of residual stresses and imperfect bonding on the initial yield surfaces and inelastic response of [0] and [± 45], SCS-6/Ti-15-3 laminates loaded by different combinations of stresses. The generated analytical predictions will be compared with the experimental results.

The experimental program comprises generation of initial yield surfaces, subsequent stress-strain curves and determination of failure loads of the SCS-6/Ti-15-3 tubes under selected loading conditions. The results of the analytical investigation will be employed to define the actual loading paths for the experimental program. A brief overview of the experimental methodology is given herein. This includes the test capabilities of the Composite Mechanics Laboratory at the University of Virginia, the SCS-6/Ti-15-3 composite tubes secured from McDonnell Douglas Corporation, a test fixture specifically developed for combined axial-torsional loading, and the MTS combined axial-torsion loader that will be employed in the actual testing.

YIELDING OF SCS-6/TI-15-3 MMC UNDER BIAXIAL LOADING

by

Carl T. Herakovich
Marek-Jerzy Pindera
Farshad Mirzadeh

Civil Engineering Department
University of Virginia

Supported by : Mechanics of Materials Branch

Technical monitor : W. Steven Johnson



OBJECTIVES

Long-term

- Inelastic response of metal matrix composites in a wide temperature range under arbitrary, biaxial loading

Short-term

- Characterization of the response of SCS-6/Ti-15-3 tubes under biaxial loading
 - [0] tubes
 - $[\pm 45]_s$ tubes
 - initial yielding
 - inelastic response
 - failure

METHODOLOGY

- Analytical/experimental approach

Analysis

- Micromechanical modeling of lamina response
 - Method of cells (Jacob Aboudi, Tel-Aviv University)
- Macromechanical modeling of laminate response
 - Method of cells + tube analysis
 - Method of cells + laminate analysis
- Initial yield surfaces
- Stress-strain response

METHODOLOGY

Experiment

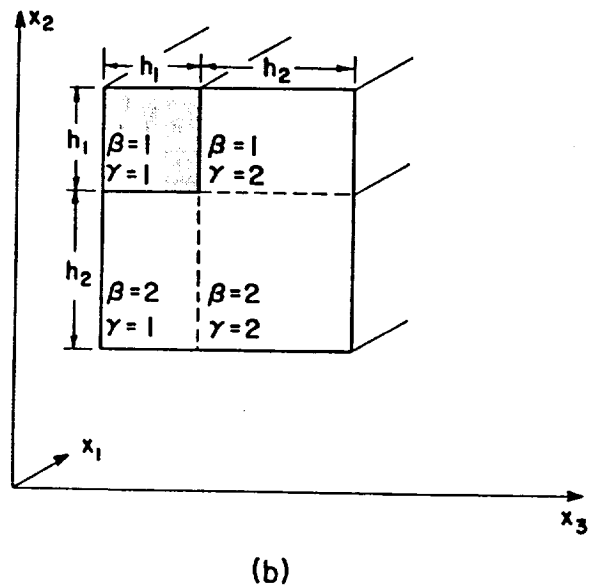
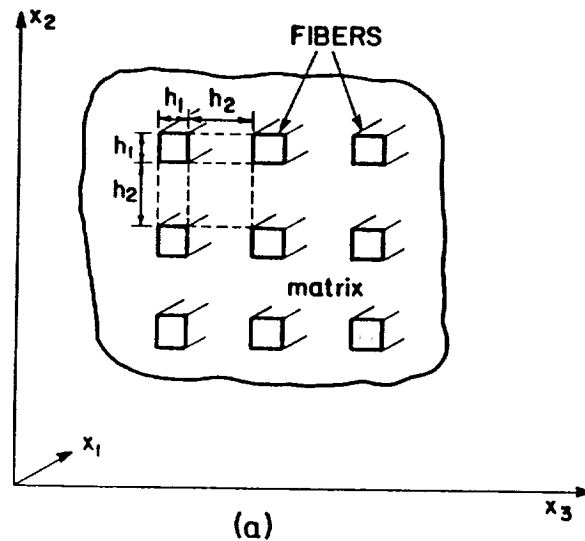
- Biaxial loading of SCS-6/Ti-15-3 tubes
 - room and elevated temperatures
 - different loading paths

ANALYTICAL INVESTIGATION



UVA
APPLIED
MECHANICS

METHOD OF CELLS



Doubly periodic array of cells

METHOD OF CELLS

- Repeating unit cell array
- Square geometry
 - square fiber
 - three matrix subcells
- Linear displacement field in each subcell
- Averaging process
 - microstructure \rightarrow continuum
- Closed form expressions

METHOD OF CELLS

Capabilities

- elastic moduli
- initial yield surfaces
- elastoplastic response
- viscoelastic response
- thermal loading
- temperature-dependent properties
- imperfect bonding : R_n and R_t parameters
 - R_n : normal interfacial compliance
 - R_t : tangential interfacial compliance

CONSTITUENT RESPONSE

- Linear elastic fibers
- Initial yielding : Von Mises matrix

$$f(\hat{S}_{ij}^{(\beta\gamma)}) = \frac{1}{2} \hat{S}_{ij}^{(\beta\gamma)} \hat{S}_{ij}^{(\beta\gamma)} - \frac{1}{3} \gamma^2 = 0$$

- Inelastic response : Bodner-Partom matrix

$$\dot{L}_{ij}^{(\beta\gamma)} = \Lambda_{(\beta\gamma)} \hat{S}_{ij}^{(\beta\gamma)}, \quad \beta + \gamma \neq 2$$

$$\Lambda_{(\beta\gamma)} = D_0 \exp \{ -\hat{n} [Z_{(\beta\gamma)}^2 / (3J_2^{(\beta\gamma)})]^n \} / [J_2^{(\beta\gamma)}]^{1/2}$$

$$Z_{(\beta\gamma)} = Z_1 + (Z_0 - Z_1) \exp [-m W_p^{(\beta\gamma)} / Z_0]$$

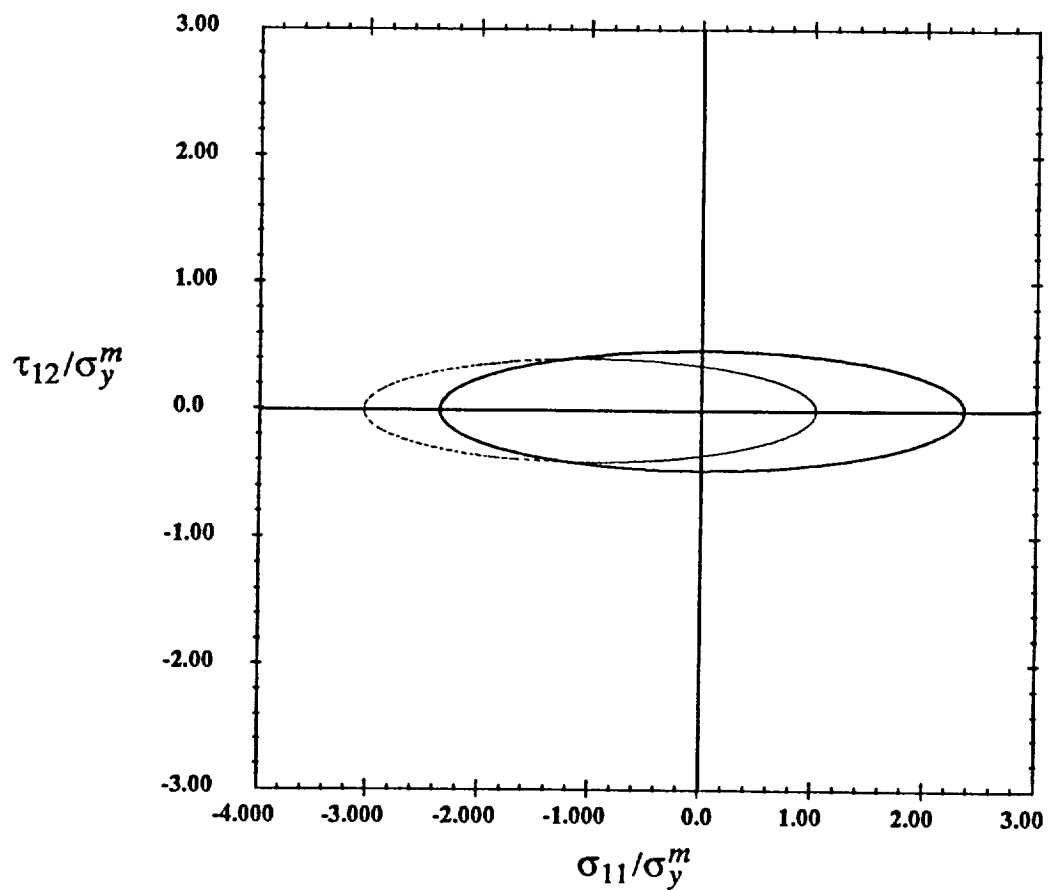
INITIAL YIELD SURFACE

SCS-6/Ti 15-3

$(0)_4 V_f=0.4$

— $\Delta T=0^\circ F, R_n=0, R_t=0$

..... $\Delta T=-1800^\circ F, R_n=0, R_t=0$



Unidirectional lamina

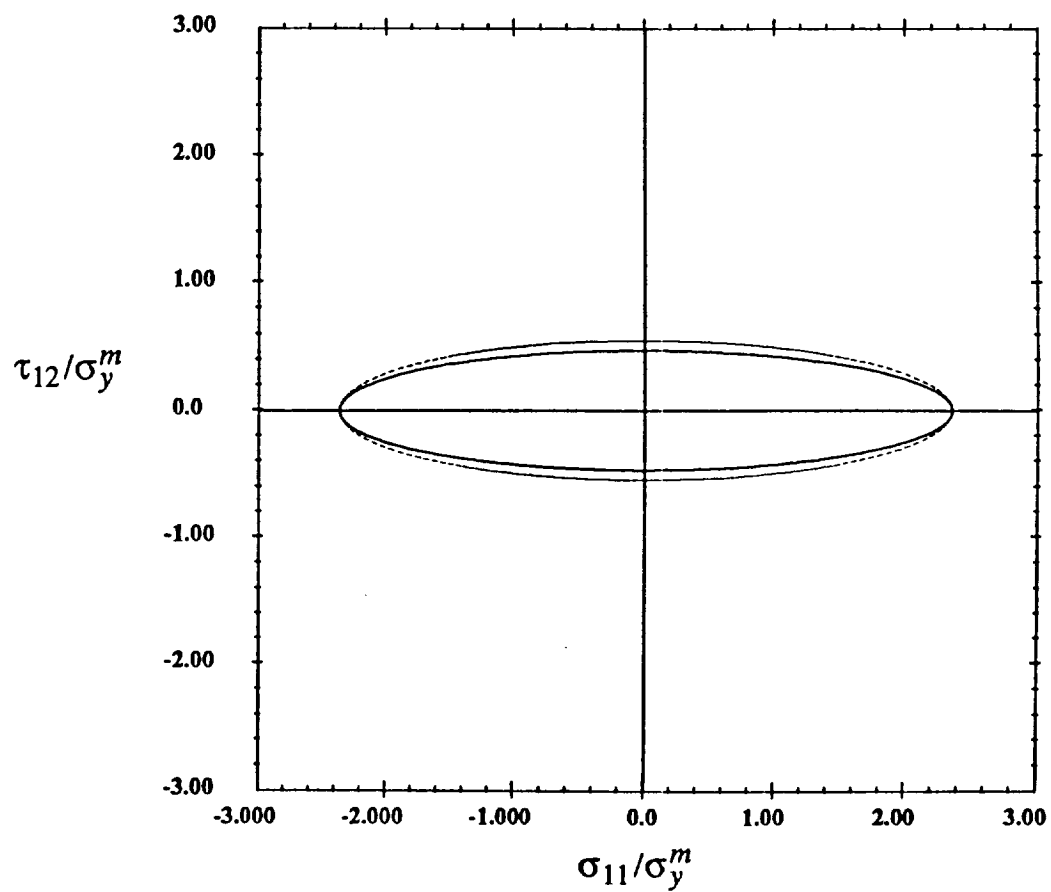
INITIAL YIELD SURFACE

SCS-6/Ti 15-3

$(0)_4 V_f=0.4$

— $\Delta T=0^\circ F, R_n=0, R_t=0$

..... $\Delta T=0^\circ F, R_n=0, R_t=6E-5$



Unidirectional lamina

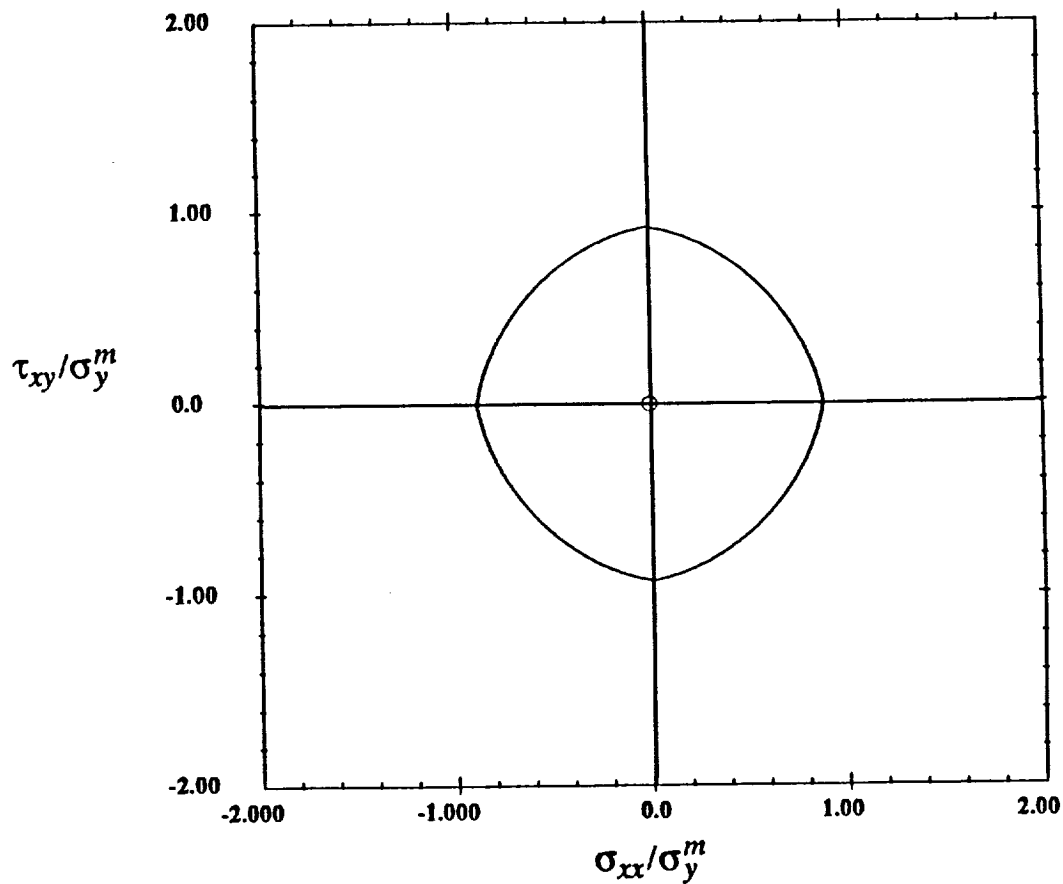
INITIAL YIELD SURFACE

SCS-6/Ti 15-3

$(\pm 45)_s$, $V_f=0.4$

— $\Delta T=0^\circ F$, $R_n=0$, $R_t=0$

..... $\Delta T=-1800^\circ F$, $R_n=0$, $R_t=0$



$[\pm 45]_s$ angle-ply laminate

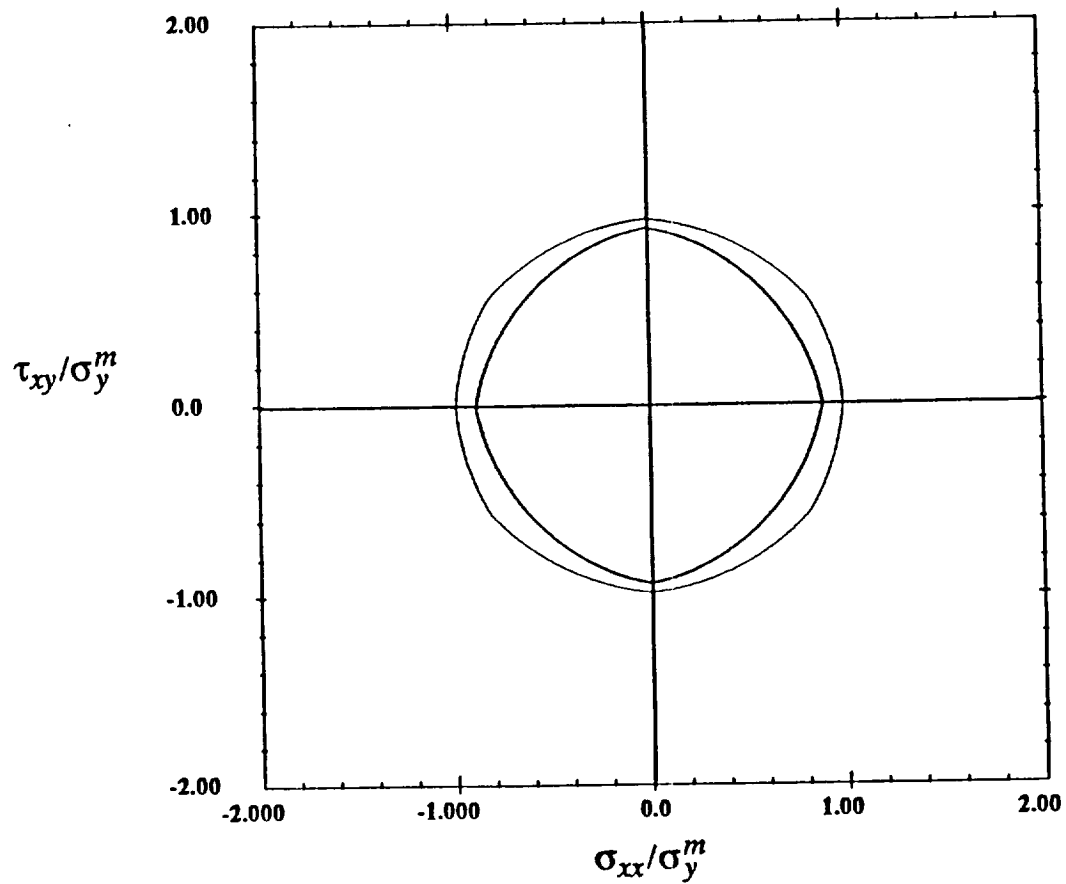
INITIAL YIELD SURFACE

SCS-6/Ti 15-3

$(\pm 45)_s V_f=0.4$

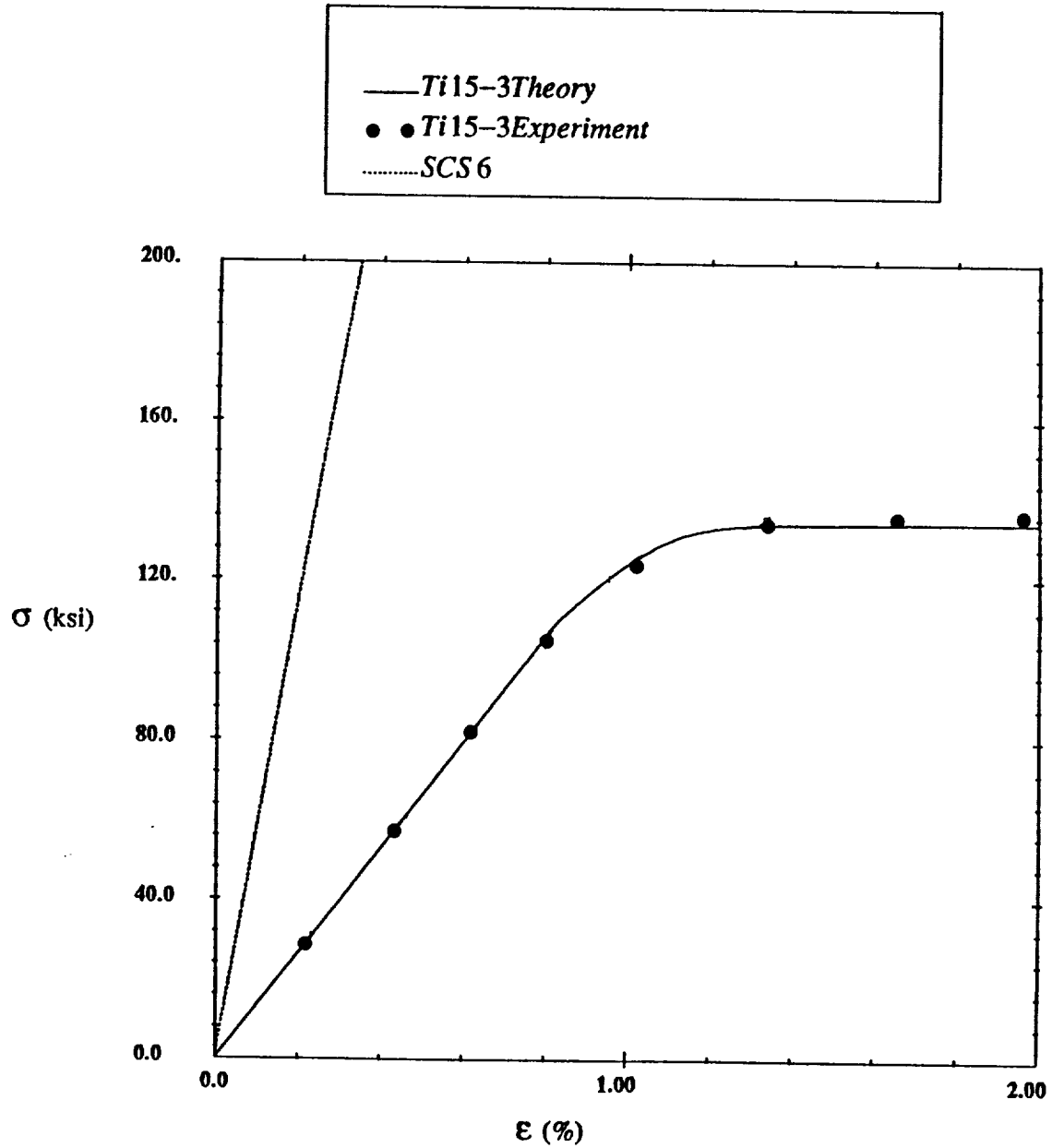
$\Delta T=0^\circ F$

— $R_n=0, R_t=0$
..... $R_n=6E-6, R_t=6E-5$



$(\pm 45)_s$ angle-ply laminate

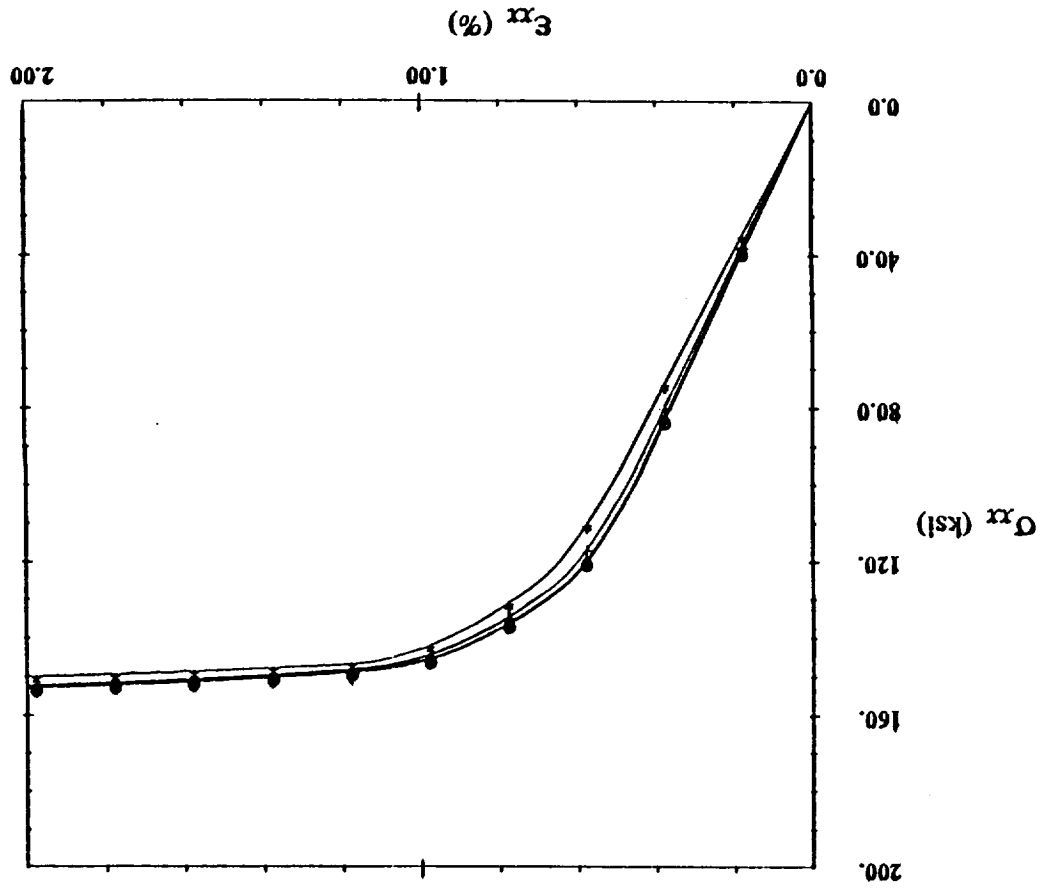
INELASTIC RESPONSE



Constituent response

INELASTIC RESPONSE

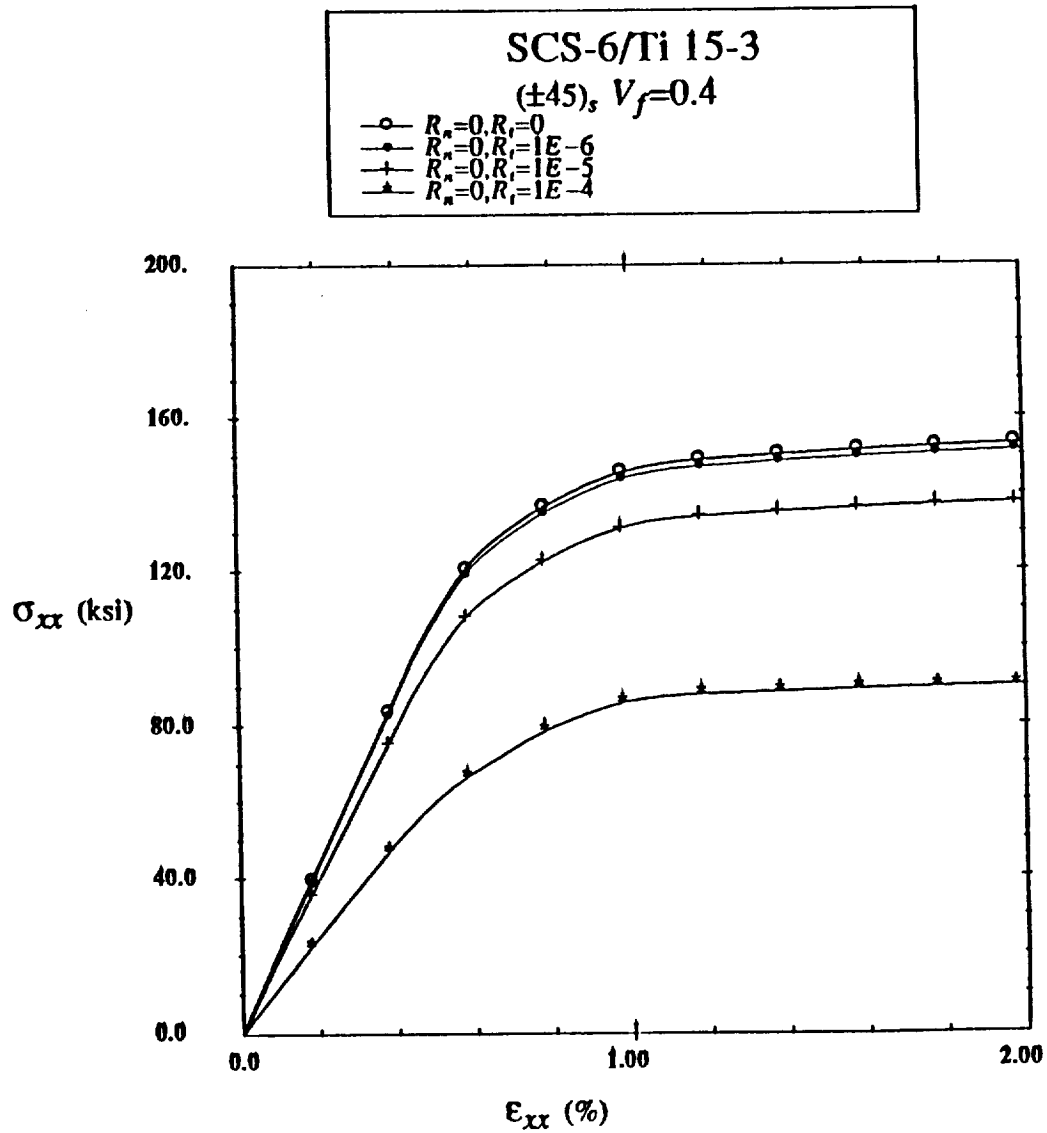
SCS-6/Ti 15-3
 $(\pm 45)_s$, $V_f = 0.4$
 $R_n = 0, R_t = 0$
 $R_n = 1E-6, R_t = 0$
 $R_n = 1E-5, R_t = 0$
 $R_n = 1E-4, R_t = 0$



$(\pm 45)_s$ angle-ply laminate response



INELASTIC RESPONSE



$[\pm 45]_s$ angle-ply laminate response

ANALYTICAL RESULTS - SUMMARY

- Initial yielding

- Residual stresses : translation and decrease in the size of initial yield surfaces, more pronounced effect on initial yielding of $[\pm 45]_s$ laminates than $[0]$ laminae
- Imperfect bonding : increase in the size of initial yield surfaces, more pronounced effect on $[\pm 45]_s$ laminates than $[0]$ laminae

- Inelastic response

- Imperfect bonding : reduction in the initial elastic moduli and subsequent inelastic response, loading direction dependent

EXPERIMENTAL INVESTIGATION

Material:

SCS6/Ti15-3

Ti15-3 \equiv Ti - 15V - 3Cr - 3AL - 3Sn

Geometry:

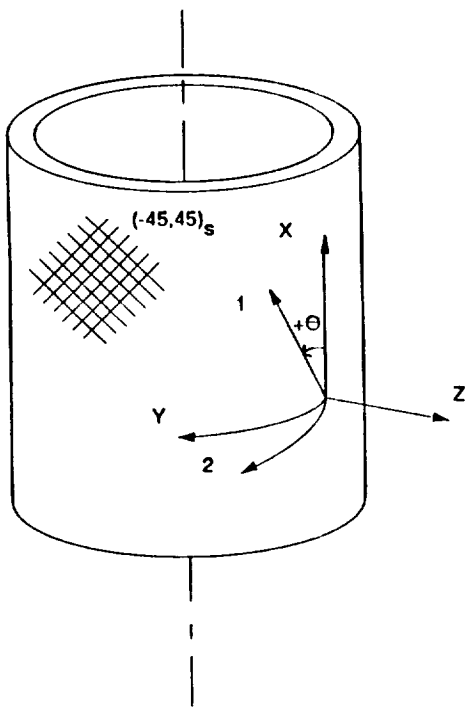
A: Six Tubes $D=4"$, $L=12"$, $t=0.032"$

B: Four Tubes $D=1.5"$, $L=7"$, $t=0.032"$

Stacking Sequence:

A: $[\pm 45]_s$

B: $[0]_4$



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Loading:

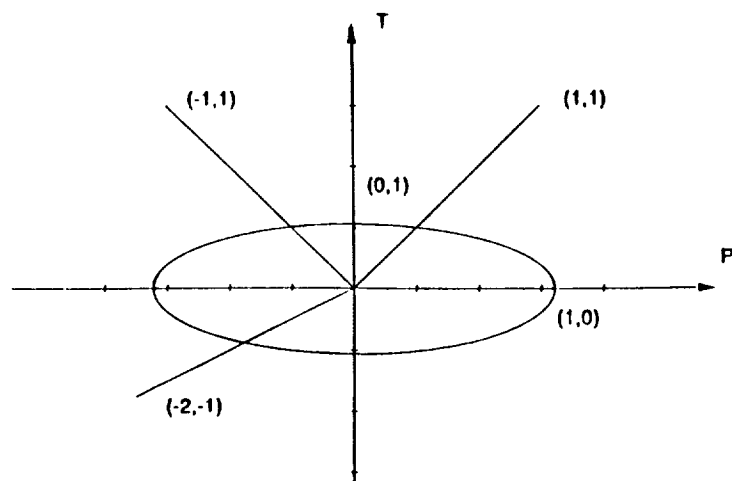
- 1 - Axial (Tension, Compression)
- 2 - Torsional (Positive, Negative)
- 3 - Internal Pressure
- 4 - Combinations of 1, 2, and 3

Environment:

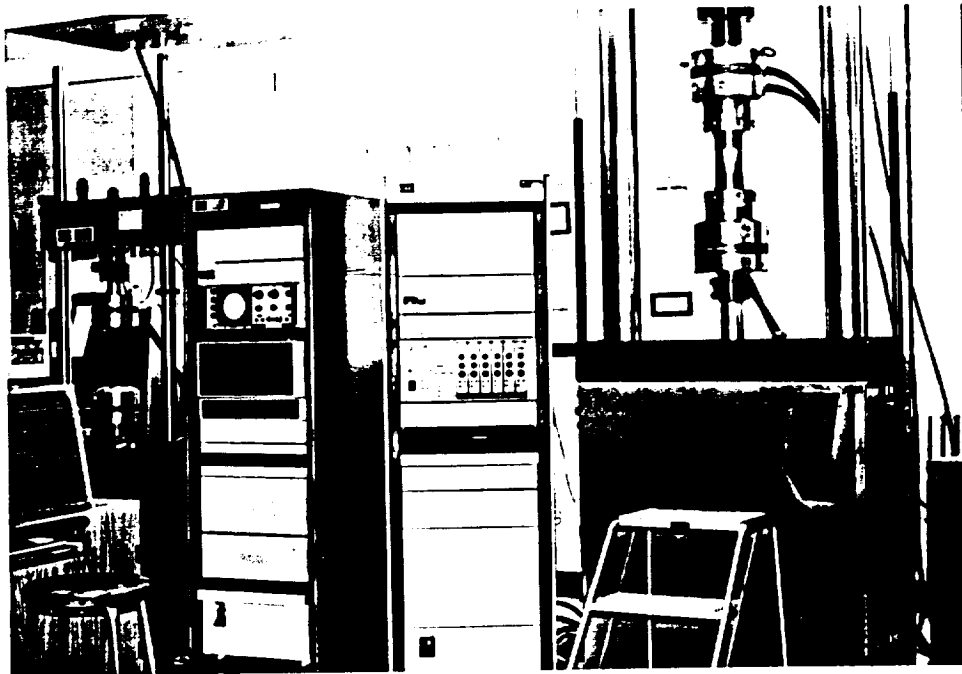
A & B: Room temperature

A: Elevated temperature
 $\leq 425^{\circ}\text{C}$ (800°F)

B: Elevated temperature
 $\leq 1700^{\circ}\text{C}$ (3100°F)



COMPOSITE MECHANICS LAB AT UVA



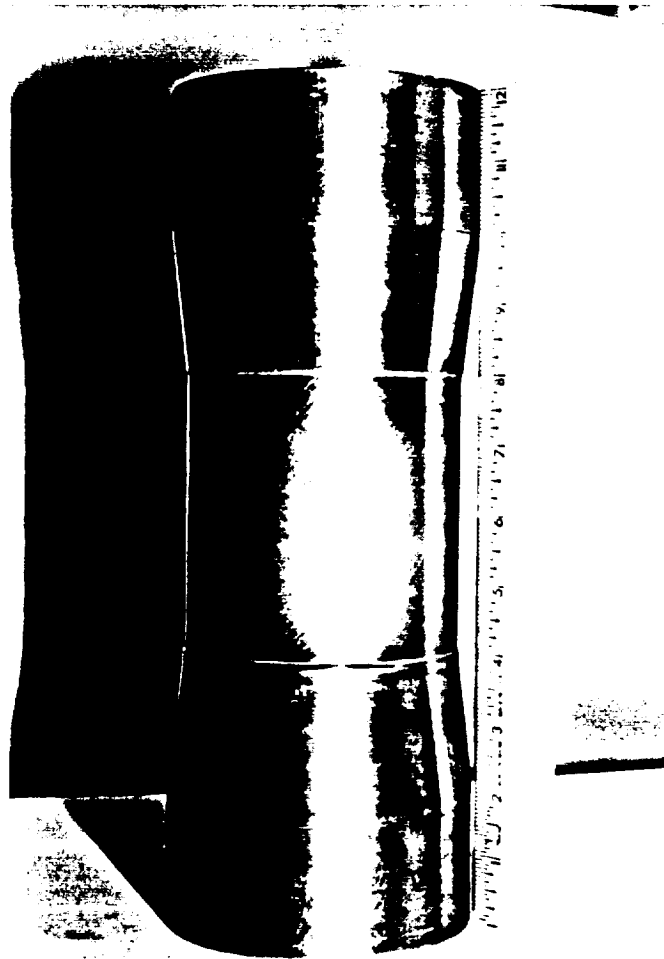
UVA
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MECHANICS

COMPOSITE MECHANICS LAB AT UVA



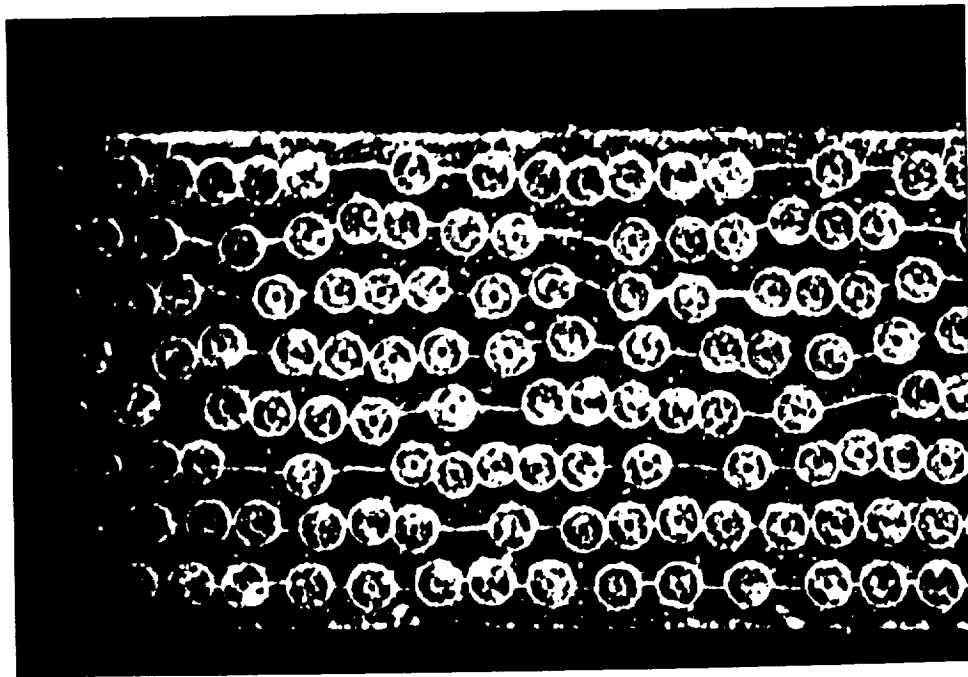
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SCS6/Ti15-3 TUBE



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SCS6/Ti15-3 PHOTOMICROGRAPH

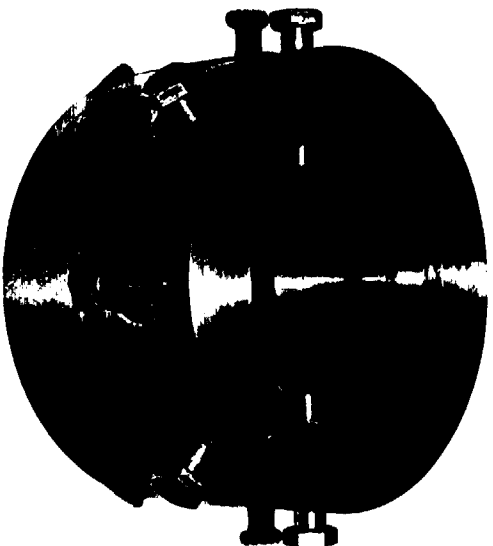


TUBE FIXTURE



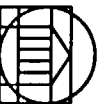
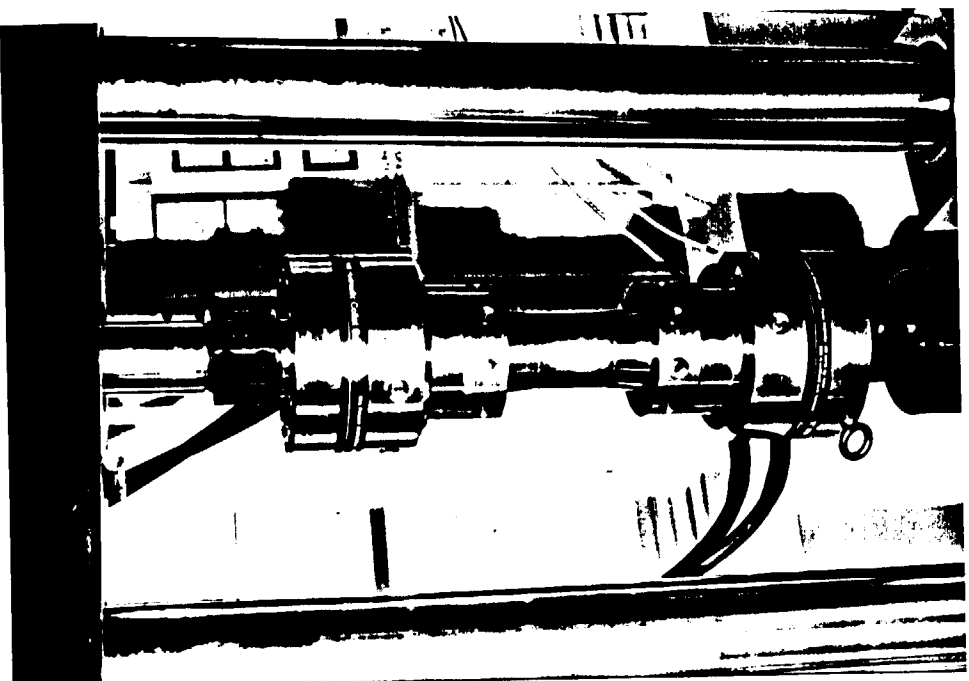
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MECHANICS

TUBE FIXTURE

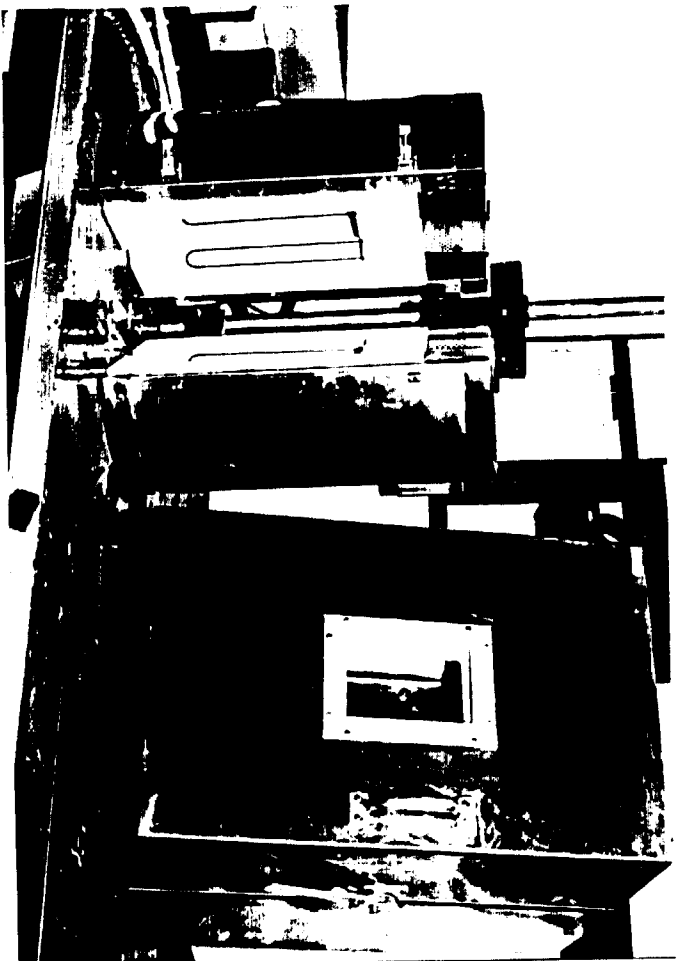


UVA
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MECHANICS

SCS6/Ti15-3 TUBE IN MTS AXIAL-TORSION LOAD FRAME



ATS OVENS



UVA
APPLIED
MECHANICS

PRESENT AND FUTURE WORK

- Analytical

- Further exercise micromechanics model at the lamina and laminate level
- Extend existing composite tube model to metal matrix composites

- Experimental

- Generate initial yield surfaces at room and elevated temperatures
- Generate stress-strain curves under biaxial loading
- Determine failure loads for selected loading paths

- Correlate theory and experiment



